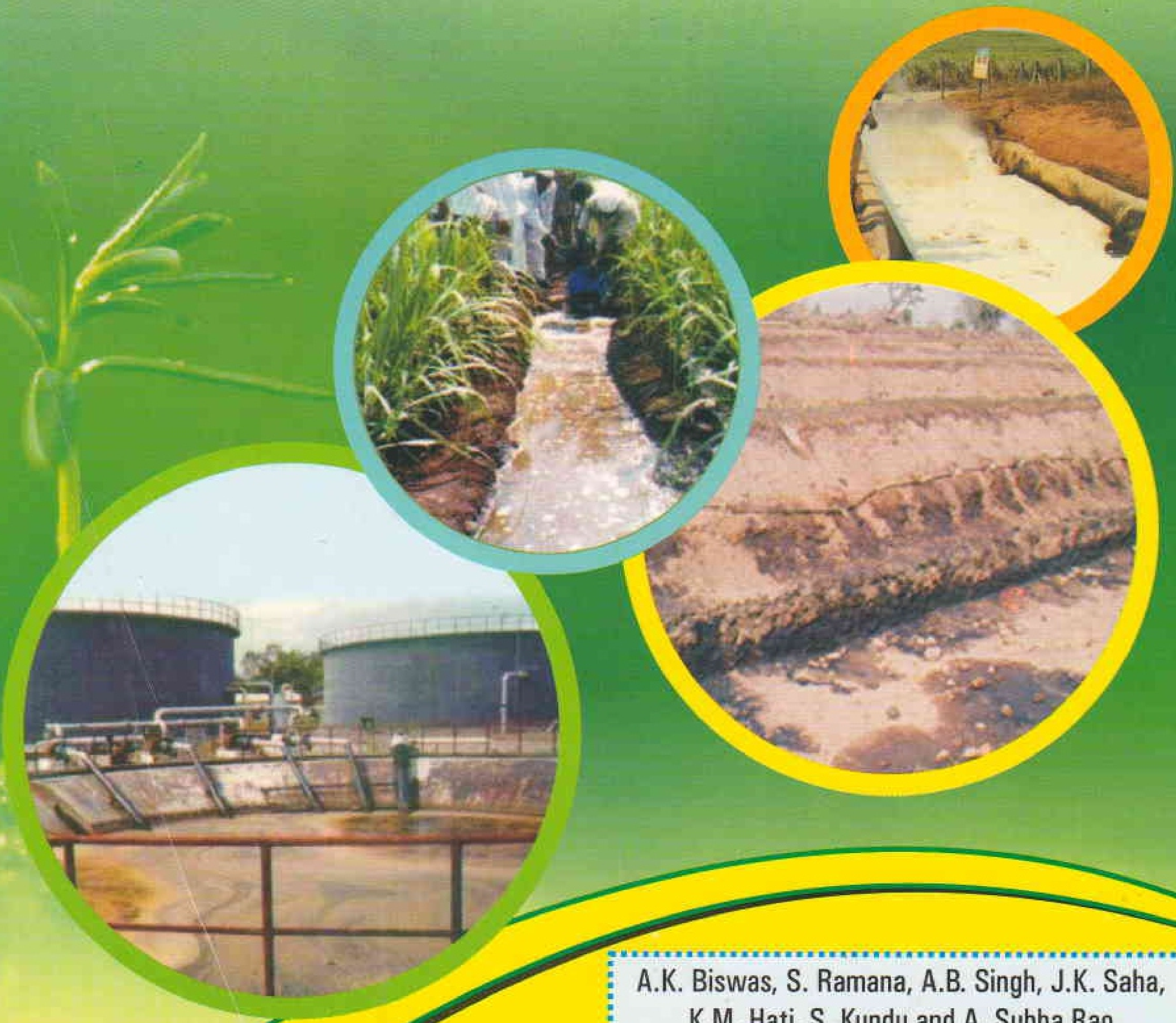
IISS Research Bulletin

SAFE USE OF DISTILLERY EFFLUENTS IN AGRICULTURE



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Foreword

Distillery spent wash is the unwanted residual liquid waste generated during alcohol production and pollution caused by it is one of the most critical environmental issues. Despite standards imposed on effluent quality, untreated or partially treated effluent very often finds access to water courses. The distillery wastewater with its characteristic unpleasant odour and high organic pollutant load poses a serious threat to the water quality in several regions around the globe. The ever-increasing generation of distillery spent wash on the one hand and stringent legislative regulations of its disposal on the other has stimulated the need for developing new technologies to process this effluent efficiently and economically.

A number of clean up technologies have been put into practice and novel bioremediation approaches for treatment of distillery spent wash are being worked out. Potential microbial (anaerobic and aerobic) as well as physicochemical processes as feasible remediation technologies to combat environmental pollution are being explored. An emerging field in distillery waste management is exploiting its nutritive potential for production of various crops, and a multi-disciplinary team of scientists from Indian Institute of Soil Science, Bhopal has done commendable job in this direction.

I congratulate all the project workers and Director for bringing out the results of this project in the form of a bulletin. This bulletin presents an overview of the pollution problems caused by distillery spent wash, changes in physical, chemical and biological properties of the soil and crop productivity due to its continuous use, and the prescriptions and technologies developed at IISS, Bhopal for its safe use in agriculture. . I am sure it will be useful to the distilleries, consultants as well as all those who are interested in developing cost effective technologies for treatment and safe disposal of distillery effluents.

(A.K. Singh)
Deputy Director General (NRM),ICAR
New Delhi

Date : January 14, 2011
Place : New Delhi

Preface

Distilleries are one of the most important agro based industries in India producing alcohol from molasses, a by-product from sugar factories. More than 90% ethanol in India is mainly produced by fermentation of diluted molasses employing different microbial strains. The demand for alcohol in India has grown up from 285 distilleries producing 1.5 billion litres of alcohol per year in 1998-99 to 319 distilleries producing 3.3 billion litre of alcohol in 2006-07. Consequently a huge quantity of wastewater is being produced which has an estimated nutrient potential to the tune of 80000 tonnes of nitrogen and 520000 tonnes of potassium apart from organic matter and other essential plant nutrients, which generally go down the drain once it is discharged into water courses.

The technologies currently used by distilleries tor treatment of this wastewater are bio-methanation followed by two-stage biological treatment and disposal in water, concentration and incineration. These technologies treat the wastewater up to a certain level. However, there are limitations posed by these technologies for full compliance of prescribed standards. These limitations are either due to high cost of treatment or inherent inability of technology to remove certain pollutants like total dissolved solids and colour to safe and acceptable limits for disposal into surface water or on land. In the absence of foolproof technology for treatment of the effluent, its use in agriculture seems to be the only alternative means which is also the most economically and environmentally viable solution for the problem faced by the generation of large volumes of effluent from distilleries.

A multi-disciplinary team of scientists from IISS, Bhopal has made consorted efforts to understand the risks and environmental impact of recycling distillery effluents in agro-ecosystems. I heartily congratulate the project team for their commendable efforts in generating useful information on safe use of distillery effluents in agriculture. I hope the information and data documented in this bulletin will be of immense help to the administrators, policy makers, environmentalists, distillers, consultants, researchers, students and others who are interested in developing cost effective technologies for treatment and safe disposal of distillery effluents.

(A. Subba Rao)
Director
Indian Institute of Soil Science

Date: January 14, 2011
Place : Bhopal

Acknowledgements

One man's tipple could be another man's poison, especially if the distillery producing our drink loads its surrounding areas with polluting effluents. It turns out that many distilleries across India dispose of effluents by dumping them into their backyards, thereby threatening the natural fertility of the soil and potable groundwater in the area. Distillery effluent is a valuable source of plant nutrients especially nitrogen, potassium, organic substrates, and micronutrients essential for plant growth. The efficacy of the use of distillery effluent in agriculture has been tested on experimental basis across the globe in different agro-climatic zones. Since a sizeable amount of waste still remains unutilized even after production of biogas and bio-compost with press mud and other filler materials, it is pragmatic to keep environmentally safe agri-cycling options open for disposal of distillery effluent. The direct use of effluent in agriculture needs adequate consideration, otherwise the existing practice of discharging effluent into water bodies may continue to pollute them.

In view of this a project entitled 'Environmental impact and risk assessment of use of distillery effluents in agriculture' was initiated in the Division of Environmental Soil Science, and the contents of this bulletin have been extracted from the results of this project. It is my proud privilege to thank the Council and the Institute for financial and technical assistance to carry out this work. I express my sincere thanks and gratitude to the Hon'ble Director, Dr. A. Subba Rao for his continued patronage and unstinted support and desired counseling in the execution of the project work from time to time, and Dr. S. Kundu, Head, Division of Environmental Soil Science for his encouragement in running the project.

I would like to place on record my sincerest thanks to the co-workers of the project, Dr. S. Ramana, Dr. A.B. Singh, Dr. J.K. Saha, Dr. K.M. Hati for timely and successful execution of the project work. I also take this opportunity to thank to all project workers, laboratory and field staffs involved in the project, specially Dr. P.K. Singh, Mr. D.R. Darwai, Mr. B.L. Verma. Dr. Manoj Pandey, and Mr. Kalicharan. I also owe a lot to my Divisional colleagues, other scientists of the Institute, Administrative Officer, Assistant Finance and Account Officer and other office staffs for their help, interactions and suggestions during the course of the project. I also place on record my profound gratitude to the owners and employees of Som Distilleries and Breweries Ltd., Bhopal for their constant support in providing different waste by-products from their distillery unit at Sehatganj, Raisen, M.P. for the study.

(A.K. Biswas)
Principal Investigator

Date: January 14, 2011

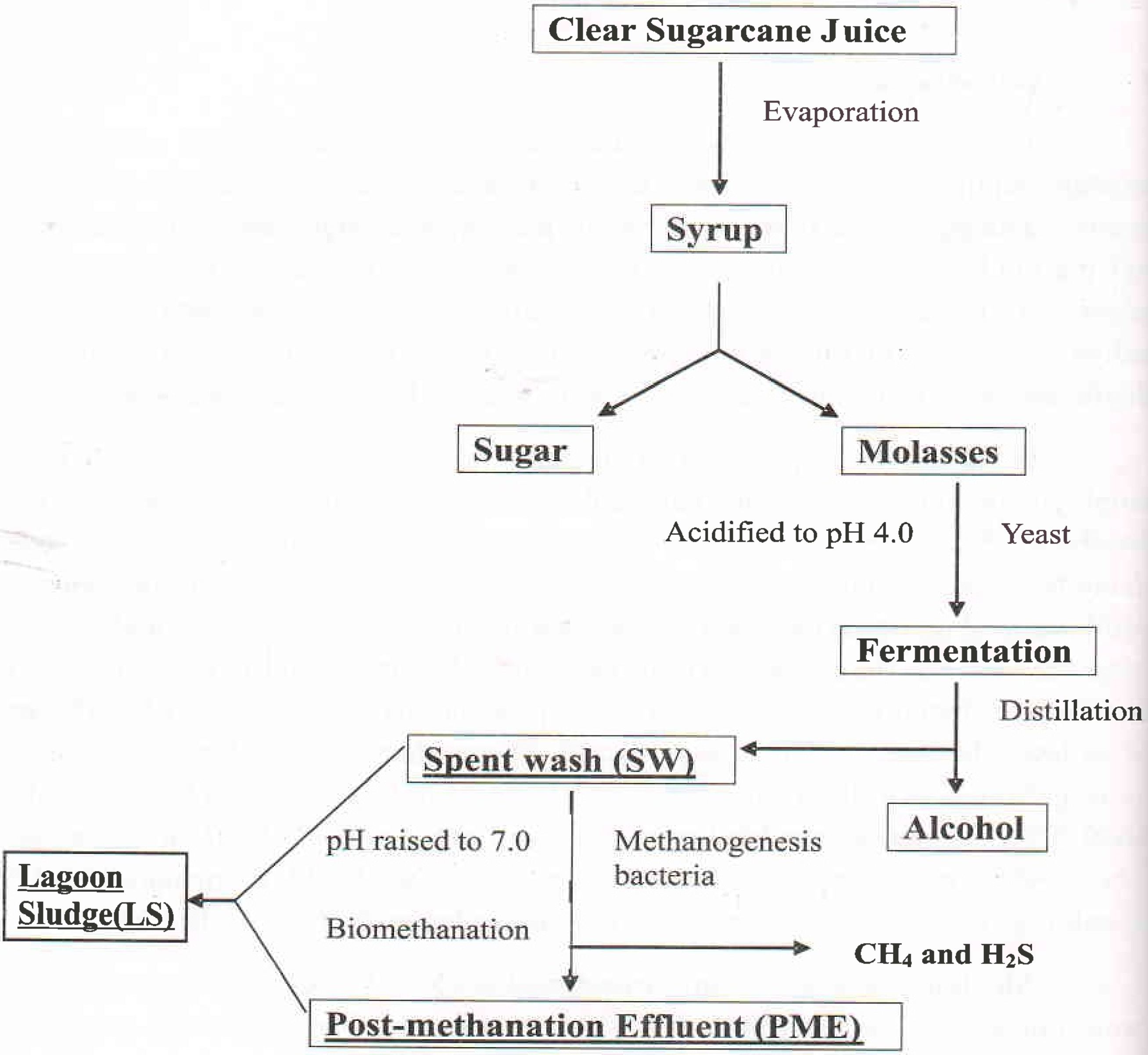

Fig. 1: A schematic diagram of production of ethanol from molasses

2. Present Production Status of Distillery Wastes

Molasses is used as a raw material in the distillery industries where alcohol is produced from two types of fermentation processes, Praj type and Alfa Laval distillation. In Praj type, for one liter of alcohol produced about 12-15 liters of waste water (spent wash) are generated, whereas, in the Alfa Laval continuous fermentation and distillation process only 7-8 liters of waste water per liter of alcohol are produced as it uses boilers for concentrating the effluents.

When India became independent in 1947, the production capacity of alcohol was 60 million liters. This has now grown by many folds. At present, there are 319 distilleries in India with an installed capacity of 3.25 billion liters of alcohol. Consequently, the wastewater generation from distilleries has gone up to 40 billion litres annully. Sugar-cane growing states of Uttar Pradesh and Maharashtra have the highest installed capacity constituting more than 40% of the installed capacity followed by Madhya Pradesh (14.2%) and Tamil Nadu (9.7%) (Uppal, 2004) .

3. Environmental Risks of Disposal in Waterways

Distillery wastewater poses a serious threat to water quality in several regions of the country. Lowering of pH value of the stream, increase in organic load, depletion of oxygen content, destruction of aquatic life and bad smell are some of the major pollution problems due to distillery wastewater. The high BOD causes depletion of dissolved oxygen and proves very harmful to aquatic life. The addition of distillery effluents to river results in high concentration of organic matter and salts in the river which is responsible for decrease in the dissolved oxygen and pH and the increase in BOD, COD levels and total dissolved solids in river water. Instances of large scale fish mortality in river Gomti due to distillery effluents have been reported. Several authors found high sensitivity of some freshwater fish to diluted spentwash. Joshi et al. (1996) noticed groundwater contamination by effluents with high BOD and salt content near the lagoon sites in most of the distilleries. In some cases, particularly in Maharashtra, the colour problem in groundwater is so acute that distilleries have to provide potable water to the surrounding villages. The problem has been overcome at some of the sites by lining the lagoons and ensuring regular use of effluents for irrigation on a larger area under well devised agronomic plan, resulting in minimum retention time in the lagoons.

4. Chemical Characteristics and Manurial Value

The distillery wastewater is characterized by its colour, high temperature, low pH, high ash content and contains high percentage of dissolved organic and inorganic matter of which 50% may be present as reducing sugars. It contains about 90-93% water and 7-10% solids; sugar being 2-20% and protein 10-11% in the dry spent wash. The metals present in spent wash are Fe-348 mg/L, Zn-4.61 mg/L, Cu-3.65 mg/L, Cr-0.64 mg/L, Cd-0.48 mg/L and Co-0.08 mg/L with electrical conductivity in the range of 15-23 dSm^{-1}. Indian spent wash contains very high amounts of potassium, calcium, chloride, sulphate and BOD (around 50,000 mg/L) compared to spent wash in other countries. Organic compounds extracted from spent wash using alkaline reagents are of humic in nature similar to those found in the soil excepting that fulvic acid predominates over humic acid (Chhonkar et al., 2000).

The population equivalent of distillery wastewater based on BOD has been reported to be as high as 6.2 billion which means that contribution of distillery waste in India to organic pollution is approximately 6-7 times more than the entire Indian population. Therefore, despite stringent standards imposed on effluent quality, the untreated or partially treated effluents very often find access to water courses. The spreading of the effluent along the marginal lands surrounding distilleries is a common sight. The retention of effluent in open anaerobic lagoons and solar drying ditches is responsible for the odour one encounters while passing through a distillery. Thus the distilleries in India have also been responsible for the pollution of the air, water and land.

The chemical analysis of untreated and treated spent wash (hereinafter referred to as 'SW' and 'PME', respectively) clearly showed their potential manurial value (Table 1). Even application of 1 ha-cm effluent to the soil can meet the N, P, K and S requirements of most of the agricultural crops. The SW is acidic (pH 4.2) in nature

Table1: Chemical composition of untreated (SW) and treated spent wash (PME)

Parameter	SW	PME	Parameter	SW	PME
pH	4.2	7.4	Total N (g L^{-1})	2.02	1.310
EC (dS m^{-1}):			Ammoniacal-N (g L^{-1})	1.254	0.675
effluent : water = 1:69	0.74	0.55	Nitrate-N (g L^{-1})	trace	0.013
effluent : water = 1:24	1.72	1.42	Total P (g L^{-1})	0.24	0.132
effluent : water = 1:12	3.24	2.39	Organic P (g L^{-1})	0.139	0.068
effluent : water = 1:9	3.97	3.25	Total K (g L^{-1})	13.0	11.50
effluent : water = 1:6	4.90	4.05	Water soluble K (g L^{-1})	7.9	8.90
effluent : water = 1:3	7.60	7.01	Total S (g L^{-1})	2.82	0.852
effluent : water = 1:2	9.80	9.20	Sulphate-S (g L^{-1})	1.31	trace
effluent : water = 1:0	25.30	25.06	Chloride (g L^{-1})	4.05	3.49
Total Solid (g L^{-1})	98.0	43.0	BOD (mg L^{-1})	36000	3960
Organic C (g L^{-1})	37.5	13.5	COD (mg L^{-1})	113240	39252

which is neutralized by some alkali amendments before it is fed to the biodigestion plant for the production of methane and elemental S. Therefore, PME is neutral (pH 7.4) in reaction. A comparison of chemical composition of SW and PME (Table 1) shows that in respect of all chemical properties the former has higher values than the latter. Although the EC of undiluted SW and PME were similar, at higher dilution the EC of SW was higher indicating that electrical conduction was much more suppressed in SW due to inter-molecular attraction and/or presence of organic molecules.

5. Bioenergy Potential

Spent wash, which is often termed as 'distillers' distress', happens to be a potential source of renewable energy. When treated anaerobically, this 'liquid gold' releases millions of kilocalories in the form of methane rich biogas that can be fed into boiler or biogas engines to generate electricity. The total effluent generated by 319 distilleries in a year amounts to nearly 40 billions liters which has a potential of producing 1100 millions cubic meter of biogas annually. This biogas normally contains 60% methane gas which is a well recognized fuel gas with minimum air pollution potential. If this source of energy is tapped, it will fetch additional energy units worth 5 trillion kilocalories annually. Besides, the post-methanation effluent (PME) can provide 2, 44,000 tonnes of potassium, 12,200 tonnes of nitrogen and 2,000 tonnes of phosphorus annually (Table 1). Thus the manurial potential of the effluent can be measured by the fact that one year effluent can meet the potassium requirement of 1.5 million hectare land, nitrogen requirement of 0.12 million hectare land and phosphorus requirement of 0.02 million hectare land if two crops are taken in a year. This is very significant in Indian context for which more and more distilleries are adopting this technology. Out of 319 distilleries, 129 have completed the construction of biomethanation digester for the primary treatment of the effluent, in 49 it is under construction and the remaining are under planning stage.

6. Impact Assessment in Agriculture

The disposal of spent wash, a distillery waste, has long been a problem for the industry. On the other hand, it is reported to have good fertilizer value and a very rich source of organic matter. But it is presumed that although the effluent may facilitate better yields at the beginning due to its richness in nutrients, its continuous and indiscriminate use or abuse may cause accumulation of salts endangering the soil productivity and quality. With this background a project was initiated at IISS, Bhopal to devise suitable management prescriptions for harmless utilization of this waste product in agriculture keeping in view the long-term implications of its use on physical, chemical and biological soil health. Results obtained in the project are annexed herewith.

6.1 Urease activity and urea hydrolysis

Application of 2.5, 5.0 and 10.0 ha-cm of spent wash to the soil 37 days before sampling showed 46.1, 63.3 and 98.0% increase in urease activity over control, whereas same levels of spent wash applied to soil 22 days before soil sampling showed 34.9, 60.2 and 73.5% increase in urease activity over control. However, there was marginal improvement in the urease activity in the soil to the tune of 11.4 and 21.4% over control when 2.5 and 5 ha-cm of spent wash was applied only 7 days before soil sampling (Table 2). The results thus showed that at each level of spent wash application, shorter the period of soil sampling the smaller was the magnitude of increase in urease activity. The easily oxidisable C added to the soil through spent wash might have resulted in increased microbial activity vis-a-vis urease activity in soil and, therefore, the soil samples collected 37 days after application of spent wash showed higher urease activity.

Table 2: Urease activity of the soil as affected by the rate and time of spent wash (SW) application

Treatment	Urease activity (mg urea kg^{-1} h^{-1})	% increase in urease activity
T_1	77.0	-
T_2	115.4	46.1
T_3	106.6	34.9
T_4	88.0	11.4
T_5	129.0	63.3
T_6	126.5	60.2
T_7	95.9	21.4
T_8	156.5	98.0
T_9	137.0	73.5
CD (P=0.05)	9.5	-

The rate of urea hydrolysis in the spent wash treated soil collected 37 days after application followed the first order kinetics. The urea hydrolysis rates differed markedly depending on the rate of application of spent wash to the soil (Table 3). The first order rate constant 'k' in control soil was 0.043 h^{-1}, which increased to 0.068, 0,079 and 0.098 h^{-1} with the application of 2.5, 5.0 and 10.0 ha-cm of spent wash to the soil, respectively. Time taken for the hydrolysis of 90% of applied urea decreased from 53.4 h in control soil to 33.8, 29.1 and 23.4 h on application of 2.5, 5.0 and 10.0 ha-cm of spent wash to the soil, respectively.

Table 3: Rate of urea hydrolysis in soil as affected by rates of post-methanated effluent (PME) application

Treatment	Rate constant 'k'(h^{-1})	Time taken (h) for hydrolysis of 50% of applied urea	Time taken (h) for hydrolysis of 90% of applied urea
T_1	0.0431	16.1	53.4
T_2	0.0682	10.2	33.8
T_5	0.0791	8.8	29.1
T_8	0.0985	7.0	23.4

6.2 Loss of nitrate from soil due to SW application

Three soils, namely, red, black and alluvial soils were used in this study. There were marked reductions in extractable nitrate with the increase in levels of SW application in all three soils (Table 4). In black soil, the extractable NO_3-N from the soils treated with 2.26, 4.52, 6.78 and 9.04 ha-cm spent wash were 60.6, 31.3, 15.7 and 11.1 per cent of that observed in control soil, while for alluvial soil, the corresponding values of extractable NO_3-N were 47.3, 31.5, 17.9 and 13.4 per cent, respectively. Quantitatively, extractable NO_3-N from red soil was higher as compared to black and alluvial soils, but when the extractable NO_3-N values from red soil were expressed in terms of percentage of that observed in untreated red soil; the values were more or less similar to those observed in black and alluvial soils. The extractable NO_3-N from the red soil treated with 2.26, 4.52, 6.78 and 9.04 ha-cm of spent wash were 59.4, 33.0, 19.9 and 15.0 per cent of that observed in control soil, respectively (Table 4).

In contrast to NO_3-N content, extractable NH_4-N content increased with the increase in the levels of spent wash application in all the three soils (Table 4). Total nitrogen added to the soil through 2.26, 4.52, 6.78 and 9.04 ha-cm were 202, 404, 606 and 808 mg kg^{-1} soil, respectively, while NH_4-N added to the soil were 12.5, 25.0, 37.5 and 50.0 mg kg^{-1}, respectively. At all levels of spent wash application, extractable NH_4-N was higher than the amount added through spent wash. After subtracting the values of the native NH_4-N content of the soils and added spent wash, the build-ups of extractable NH_4-N in black soil were 14.1, 15.6, 41.4, and 133.3 mg kg^{-1} soil at 2.26, 4.52, 6.78 and 9.04 ha-cm of spent wash application, respectively, while the corresponding depletion of extractable NO_3-N were 73.4, 127.8, 156.9 and 165.6 mg kg^{-1} soil, respectively (Table 4). However, in alluvial and red soils, the magnitudes of build-ups of extractable NH_4-N in soil treated with 6.78 and 9.04 ha-cm spent wash were smaller as compared to black soil, whereas at lower levels of spent wash, the values of extractable NH_4-N did not differ much. Similar to the black soil, the value of extractable NH_4-N build-ups in alluvial and red soils were much smaller than the value of NO_3-N depletion values at each level of spent wash (Table 4). In alluvial soil, at 2.26, 4.52, 6.78 and 9.04 ha-cm level of applied spent wash, the build-ups of extractable NH_4-N were 15.4, 9.8, 18.2 and 40.6 mg kg^{-1} soil while corresponding NO_3-N depletion were 104.6, 135.8, 162.7 and 171.7 mg kg^{-1} soil, respectively. In case of red soil, build-up of extractable NH_4-N to the tune of 13.2, 11.2, 5.7 and 35.0 mg kg^{-1} soil were observed in the respective spent wash treatments.

Table 4: Changes in NH_4-N and NO_3-N content in different soils treated with SW

Rate of spent wash application (ha-cm)	2M KCl extractable NH_4-N (mg kg^{-1})	Increase in NH_4-N over control (mg kg^{-1})	2M KCl extractable NO_3-N (mg kg^{-1})	Loss in NO_3-N over control (mg kg^{-1})
Black Soil				
0	8.2	-	186.2	-
2.26	34.8	14.1	112.8(60.6)*	73.4
4.52	48.8	15.6	58.4(31.4)	127.8
6.78	87.1	41.4	29.3(15.7)	156.9
9.04	191.5	133.3	20.6(11.1)	165.6
CD (P=0.05)	*7.6*		*7.3*	

Rate of spent wash application (ha-cm)	2M KCl extractable NH_4-N (mg kg^{-1})	Increase in NH_4-N over control (mg kg^{-1})	2M KCl extractable NO_3-N (mg kg^{-1})	Loss in NO_3-N over control (mg kg^{-1})
Alluvial Soil				
0	6.9	-	198.4	-
2.26	34.8	15.4	93.8(47.3)	104.6
4.52	41.7	9.8	62.6(31.5)	135.8
6.78	62.6	18.2	35.7(18.0)	162.7
9.04	97.5	40.6	26.7(13.4)	171.7
CD (P=0.05)	*4.3*		*7.1*	
Red Soil				
0	2.1	-	217.1	-
2.26	27.8	13.2	128.9(59.4)	88.2
4.52	38.3	11.2	71.7(33.0)	145.4
6.78	45.3	5.7	43.2(19.9)	173.9
9.04	87.1	35.0	32.6(15.0)	184.5
CD (P=0.05)	*5.6*		*9.32*	

*Data in the parentheses indicate the values expressed as per cent of the values observed in respective no-spent wash treatment.

6.3 Dynamics of organic C from spent wash

Application of the effluent (SW as well as PME) to the soil markedly influenced the microbial activity of the soil as indicated by increasing quantum of CO_2 evolution with the increase of spent wash application. The weekly loss values of C as CO_2 from different treatment given in Table 5 indicated differential losses of C depending upon the quantum of C added through SW. In control, the loss of C from the native organic matter was 2.71 g m^{-2} in the 1st week which gradually declined to 1.23 g m^{-2}. As the soil received additional C through spent wash, the loss of C as CO_2 stepped up to 8.20, 9.79, 12.11, 14.82 and 15.62 at R_1, R_2, R_3, R_4 and R_5, respectively, in the 1st week of incubation, indicating enhanced microbiological activity in the soil with the increase in the levels of C substrates added through untreated spent wash. The result also indicated that the enhanced microbial activities were sustained even up to 8 weeks of incubation. During the 8th week of incubation, loss of C to the tune of 5.08, 7.21, 8.68, 11.01 and 13.13 g m^{-2} was observed in R_1, R_2, R_3, R_4 and R_5 treatments, respectively.

In the control treatment, attempt was made to find out the potentially mineralizable C of the native organic matter of the soil by plotting the 1/c and 1/t and the reciprocal of the intercept was considered as potentially mineralizable C, where `C' was the cumulative loss of C as $CO_2$ expressed as g C $m^{-2}$ in time `t' (day). It was observed that the black soil under the present experiment had 41.84 g m^{-2} or 0.186 g kg^{-1} potentially mineralizable C. The direct measurement indicated a net loss of C as CO_2 to the tune of 15.79 g m^{-2} after 8th weeks of incubation. i.e., 36.04% of the potentially mineralizable C of the soil was lost as CO_2 after 8 weeks of incubation.

Further, considering the organic C and potentially mineralizable C of the soil, it could be concluded that only 3.33% of the total organic C of the soil was potentially mineralizable indicating that the native organic carbon of the soil was very stable in nature. The cumulative loss of C in R_1 after 8 weeks of incubation markedly increased from 15.06 to 53.28 g C m^{-2}. As the level of addition of C to the soil through SW was raised by 2, 3, 4 and 5 times that of R_1, the additional losses of C from soil in R_2, R_3, R_4 and R_5 over R_1 were 10.37, 29.32, 53.10 and 62.63 g C m^{-2}, respectively. Comparing the values of C added to the soil through different levels of spent wash application and values of losses of C from the soil as CO_2 through microbial respiration, it was noted that in R_1 treatment 37.02% of the added C was lost after 8 weeks whereas in R_5 only 16.02% of the added C was lost after 8 weeks, indicating that as the levels of added C was increased, lesser was the percentage loss of added C as CO_2 through microbial respiration.

The week wise loss of C as CO_2 from PME treated soil (Table 6) showed large differences in early stage of incubation and the difference narrowed down with the passage of time. Because of the addition of organic C to the soil through PME, the loss of C increased to 6.65, 9.26, 11.95, 13.17 and 14.48 g C m^{-2} at B_1, B_2, B_3, B_4 and B_5, respectively in the 1st week of incubation, while loss of C during the 8th week from the corresponding treatments were 1.84, 2.49, 2.86, 2.99 and 3.41 g C m^{-2}, respectively. The cumulative loss of C from the soil after 8 weeks of incubation markedly increased from 15.08 g C m^{-2} in control to 25.87, 35.70, 43.19, 48.01 and 52.89 g C m^{-2} at B_1, B_2, B_3, B_4 and B_5, respectively (Table 6). At B_1, where soil received minimum amount of organic C (51.95 g C m^{-2}), 49.75% of the added C was lost as CO_2 whereas at B_5 only 20.36% of added C was lost from the soil indicating that lower the rate of organic C loading on the soil higher was the loss of C as CO_2. A parabolic relation in the form of $Y = 15.06 + 0.2299X - 0.00032X^2$ ($R^2 = 0.998^{**}$) was observed between the amount of C lost (Y) and the amount of C added (X) to soil through PME.

Table 5: Week-wise loss of C as CO_2 from the soil treated with different level of SW

Treatment	Amount of C added (g C m^{-2})	Weekly loss of C as CO_2 evolution (g. C m^{-2})								Cummulative loss of C (g C m^{-2})	% loss of added C
		1st	2nd	3rd	4th	5th	6th	7th	8th		
R_0 (control)	0	2.71	2.42	2.12	1.78	1.76	1.60	1.46	1.23	15.08	-
R_1 (0.38 ha-cm)	143.90	8.20	7.61	7.20	6.95	6.35	6.01	5.89	5.08	53.29	37.03
R_2 (0.76 ha-cm)	287.80	9.79	8.53	8.21	7.93	7.68	7.47	7.38	7.21	64.20	22.30
R_3 (1.14 ha-cm)	431.70	12.11	11.32	10.87	10.61	10.27	9.50	9.24	8.68	82.60	19.13
R_4 (1.52 ha-cm)	575.60	14.82	14.63	14.15	13.82	12.89	12.73	12.29	11.01	106.34	18.47
R_5 (1.90 ha-cm)	719.50	15.63	15.42	14.89	14.63	14.20	13.87	13.55	13.11	115.30	16.02
CD (P=0.05)		0.96	0.83	0.72	0.86	0.82	0.91	0.72	0.93	6.62	

Table 6: Week-wise loss of C as CO_2 from the soil treated with different level of PME

Treatment	Amount of C added (g C m^{-2})	Weekly loss of C as CO_2 evolution (g. C m^{-2})								Cummulative loss of C (g C m^{-2})	% loss of added C
		1st	2nd	3rd	4th	5th	6th	7th	8th		
R_0 (control)	0	2.71	2.42	2.12	1.78	1.76	1.60	1.46	1.23	15.08	-
R_1 (0.38 ha-cm)	51.95	6.65	4.03	3.06	2.84	2.69	2.47	2.29	1.84	25.87	49.75
R_2 (0.76 ha-cm)	103.90	9.26	6.45	5.05	3.75	3.16	2.83	2.71	2.49	35.70	34.35
R_3 (1.14 ha-cm)	155.85	11.95	7.99	6.20	4.17	3.64	3.32	3.06	2.86	43.19	27.71
R_4 (1.52 ha-cm)	207.80	13.17	9.41	6.88	4.62	3.97	3.60	3.37	2.99	48.01	23.10
R_5 (1.90 ha-cm)	259.75	14.48	10.53	7.41	5.26	4.32	3.87	3.61	3.41	52.89	20.36
CD (P=0.05)	-	0.84	0.58	0.45	0.33	0.29	0.20	0.23	0.21	3.27	-

Based on these results, it appeared that the microbial population of soil responded well to the C substrate applied to the soil through SW. However, the rate constant (k) for the loss of C through microbial respiration was very much dependent on the amount of C substrate added to the soil (Table 7). At R_1 where added C substrate was 143.9 g C m^{-2} the value of `K' was very high, i.e. 0.058 $wk^{-1}$ and the value of `K' steadily decreased to 0.022 wk^{-1} at R_5 where the added C was 719.5 g C m^{-2}. These results clearly indicated that residence time of the added C through spent wash in the soil was totally dependent on the magnitude of total C added to the soil. Using these 'k' value, residence time of the added C in soil at different level of spent wash application were calculated (Table 7). The results showed that it would take 11.95 to 31.5 weeks to allow 50% of the added C to be lost as CO_2 through microbial respiration following the application of untreated spent wash to the soil.

It was also noted that at each level of PME application, the cumulative loss of C as CO_2 (Y) as a function of incubation time (t) was related with the substrate C (A_0) added to the soil at the start of incubation in the form of a first order equation: $Y = A_0 (1 - e^{-kt})$, where 'k' is the rate constant (wk^{-1}) for microbial respiration. The results (Table 7) showed that the values of 'k' varied markedly ranging from 0.0786 to 0.0232 wk^{-1}, depending upon the levels of PME applied to the soil. The 'k' values decreased gradually as the levels of organic C added through PME increased. Using these 'k' values, the half-life ($t_{1/2}$) of the added C was computed and it was found that it would take 8.81 to 29.87 weeks for half of the added C to be lost as CO_2 from the soil through microbial respiration following application of PME to the soil.

Table 7: Rate constants (k) for the loss of C through microbial respiration and half life (t½) of the added C to the soil through SW and PME

SW level	k (wk^{-1})	$t_{½}$ (wk)	PME level	k (wk^{-1})	$t_{½}$ (wk)
R_1	0.058*	11.95	B_1	0.0786	8.81
R_2	0.035	19.80	B_2	0.0454	15.26
R_3	0.028	24.75	B_3	0.0336	20.62
R_4	0.026	26.65	B_4	0.0269	25.76
R_5	0.022	31.50	B_5	0.0232	29.87

6.4 *Physiological response of selected crop plants*

6.4.1 *Seed germination*

A laboratory experiment was conducted to study the effects of different concentrations (5, 10, 15, 20, 25, 50, 75 and 100%) of distillery effluent on germination percentage, speed of germination, peak value and germination value of different vegetable crop species i.e., tomato, chilli, bottle gourd, cucumber and onion. Among the five crops studied, tomato recorded the lowest germination per cent and was highly sensitive to the distillery effluent application. The germination per cent of chilli, bottle gourd and onion were at par with one another and recorded significantly higher germination values. On the other hand, cucumber was intermediate in its response to the effluent. As the concentration of the effluent increased, the germination percentage decreased significantly and beyond 50%, it was completely inhibited. Among different concentrations of the effluent, the germination per cent was significantly affected even at the lowest concentration (5%) compared to control (distilled water). In cucumber and chilli, up to 25% concentration, effluent had no effect on germination, whereas in bottle guard and tomato the effluent decreased the germination from 10% onwards (Table 8).

Significant differences were observed in speed of germination, peak value and germination value. Speed of germination was the highest in cucumber followed by onion, bottle gourd, chilli and tomato, respectively. Distillery effluent significantly decreased the speed of germination even at the lowest concentration (5%). Among different crops, onion recorded significantly higher peak value and germination value followed by bottle gourd, whereas tomato recorded significantly the lowest value. The peak value and germination values were not significantly affected at 5% concentration compared to control. As the concentration of the effluent increased, these values decreased significantly (Table 9).

On the other hand, crops belonging to Cruciferae family were also examined under the influence of distillery effluent and found that radish recorded the highest germination percentage (100%) in control followed by cauliflower (98%) and mustard (94%). However, germination percentage was at par with control up to 25% concentration among the treatments. Germination percentage declined significantly from 25 % onwards in mustard. Similar trends were also observed with speed of germination, peak value and germination value.

Table 10: Effect of distillery effluent on yield components and yield (g plant^{-1}) of soybean at harvest.

Treatment	No. of pods	Dry wt of pods (g)	Seed yield (g)	100 Seed wt(g)	HI
Control	42.75	24.70	5.20	5.95	21.04
5%	58.75	35.00	7.68	6.46	21.96
10%	60.00	35.50	8.00	6.98	22.53
15%	72.33	37.00	8.27	7.19	22.36
25%	55.75	34.33	7.26	6.34	21.16
50%	52.00	34.00	7.05	6.29	20.74
75%	48.25	33.33	6.75	5.58	20.24
100%	45.75	28.00	5.73	5.38	20.48
CD(P=0.05)	*12.27*	*4.42*	*1.64*	*1.04*	*NS*

6.5 Raising of nursery of gliricidia and biological activity of soil

To find out the possibility to use post-methanation spent wash (PME) as irrigation water cum liquid fertilizer for raising forest nursery, an experiment under screen house conditions was performed. The impact of PME on the growth, VA-mycorrhizal colonization and morphological and biochemical parameters of Gliricidia sepium saplings and biological activity of soil was investigated.

The seedlings of Gliricidia were raised in polythene bags containing mixture of soil: sand: FYM (2:1:1) for a period of one month. The one month old seedlings, as per treatment schedule (Table 11), were irrigated either with 50 ml of water or various dilutions of PME. Besides this the seedlings were irrigated with tube well water as and when necessary and maintained for a period of fourteen weeks.

6.5.1 VA-mycorrhizal colonization, chlorophyll content and growth

The VA-mycorrhizal colonization in roots of Gliricidia by indigenous propagation improved linearly and significantly with increase in the concentration of PME up to 25 per cent application (Table 11). The lowest VAM-colonization (32.30%) was observed in the plants irrigated with tube well water.

The overall vigour of Gliricidia seedlings irrigated with different concentrations of PME improved significantly over the seedlings irrigated with tube well water. Plant height and girth of the stem increased significantly up to 25 per cent concentration of spent wash application while root length increased up to 50 per cent concentration. Nodules formed on the roots of seedlings were too small to count. However, nodulation was observed to be improved in the plants receiving PME up to 25 percent of concentration. Higher concentration of PME (particularly 75 and 100%) inhibited the nodulation severely.

The dry biomass accumulation in shoots as well as roots was maximum (4.61 & 1.30 g plant^{-1}, respectively) in the seedlings watered with 25 per cent concentration of PME. These were significantly higher by 36.00 and 75.68 per cent, respectively over the dry biomass accumulated in the seedlings receiving tube well water (Table 11).

Table 11: Impact of various concentrations of post-methanation spent wash on VA-mycorrhizal colonization, growth parameters and dry biomass production in *G. sepium*

Treatment	VAM Colonization (%)	Plant height (cm)	Root length (cm)	Stem girth (cm)	Dry shoot biomass (g plant^{-1})	Dry root biomass (g plant^{-1})	Total dry biomass (g plant^{-1})
Control	32.30	45.62	28.02	0.801	3.39	0.74	4.13
5%	46.52	49.65	27.04	0.623	3.79	0.76	4.55
10%	54.12	50.78	24.86	0.687	4.00	0.76	4.76
25%	67.91	55.44	26.10	0.725	4.61	1.30	5.91
50%	70.44	48.68	28.20	0.708	2.38	0.83	3.21
75%	72.58	45.90	25.56	0.604	1.94	0.54	2.48
100%	70.09	42.70	23.44	0.525	0.87	0.34	1.21
CD (0.05)	*7.15*	*5.99*	*2.82*	*0.13*	*0.61*	*0.26*	*0.70*

Chlorophyll 'a' content in leaves of plants receiving 25 per cent concentration of PME significantly improved over the plants receiving tube well water (Table 12). However, synthesis of total chlorophyll content increased linearly, though none significantly, with increase in PME application up to 25 per cent concentration. The chlorophyll 'a' as well as total chlorophyll synthesis were found to be inhibited in the plants receiving higher concentration of PME. At higher concentration of PME application various morphological, physiological and biological parameters were inhibited. The saplings of Gliricidia receiving even 100 percent PME did not show any sign of mortality. This indicates that the Gliricidia plants may tolerate the higher levels of salt concentration present in the PME.

6.5.2 Phenol and mineral content in plant

Total phenol content increased significantly in leaves of plants irrigated with 25 per cent concentration of PME (Table 12). In roots also total phenol content increased although non-significantly due to PME application. Application of PME up to 25 per cent concentration significantly increased the total mineral content in leaves, stem and roots of Gliricidia. Total mineral content of 18.16, 10.84 and 11.70 per cent were analyzed the highest in leaves, stem and roots, respectively of the plants receiving 25, 50 and 50 percent concentration of PME, respectively.

6.5.3 Biological activity of soil

Soil health in terms of dehydrogenase activity, which is an index of biological activity improved significantly due to application of PME. 25 per cent concentration of PME supported the maximum dehydrogenase activity *i.e.* 1642.08 $g\ g^{-1}$ soil (Table 13). Acid as well as alkaline phosphatase activities were also increased significantly due to PME application up to 25 per cent concentration and the values were 543.01 and 918.85 $g\ g^{-1}$ soil respectively. The enhanced enzymatic activities clearly demonstrate the increased biological activity due to ready availability of substrate present in PME.

Table 12: Chlorophyll content in leaf tissues and total phenol, mineral and carbon contents in different plant parts of *G. sepium* as influenced by different concentrations of PME application

Treat-ment	**Chlorophyll content ($mg\ g^{-1}$ fr.wt. of leaves)**			**Total phenol ($g\ kg^{-1}$ plant)**			**Total mineral content (%)**		
	'a'	**'b'**	**Total**	**Leaf**	**Stem**	**Roots**	**Leaf**	**Stem**	**Roots**
Control	0.98	0.20	1.18	23.5	3.0	3.1	13.82	5.70	6.40
5%	1.08	0.15	1.23	26.4	3.4	4.2	13.94	7.10	9.00
10%	1.28	0.22	1.50	28.4	2.9	4.2	16.12	7.70	9.58
25%	1.30	0.24	1.55	31.2	3.0	4.7	18.16	9.30	9.62
50%	1.14	0.17	1.31	26.4	3.0	4.8	16.75	10.84	11.70
75%	0.65	0.19	0.74	28.4	3.0	4.9	16.46	11.08	10.48
100%	0.37	0.13	0.40	28.8	2.8	4.2	15.84	11.10	10.20
CD(P=0.05)	*0.31*	*NS*	*0.43*	*3.90*	*NS*	*NS*	*2.26*	*2.07*	*2.37*

6.5.4 *Soil reaction and electrical conductivity*

The conductivity values significantly increased with increase PME concentration (Table 13). The highest EC (3.93 dSm^{-1}) was recorded in the treatment that received 100% PME. This increase in EC of soil was due to the higher EC of PME (25.1 dSm^{-1}). Soil pH did not change probably due to high buffering power of the soil.

Table 13: Enzymatic activity, soil reaction, electrical conductivity and total phenol in Gliricidia raised soil receiving varying dilutions of PME

Treatment	Dehydrogenase activity (g g^{-1}soil)	Acid phosphatase activity (g g^{-1}soil)	Alkaline phosphatase activity (g g^{-1}soil)	pH (1:2.5; soil: water)	EC (1:2 soil: water) (dSm^{-1})	Phenol (g kg^{-1} soil)
Control	709.03	364.35	503.97	7.19	0.16	2.71
5%	873.73	402.08	509.24	7.10	1.43	3.38
10%	1531.54	499.71	844.45	7.25	1.68	3.83
25%	1642.08	543.01	918.85	7.26	2.61	4.29
50%	1153.83	443.92	687.45	7.32	2.88	4.43
75%	1120.92	346.60	650.05	7.51	2.93	5.28
100%	1027.75	329.41	600.27	7.61	3.93	6.34
CD (0.05)	*90.71*	*36.49*	*87.25*	*NS*	*0.40*	*0.77*

6.6 *Relative efficacy of different distillery wastes*

6.6.1 *Growth and quality parameters of maize-chickpea and groundnut-wheat systems*

Field experiments were conducted at the Indian Institute of Soil Science, Bhopal during 2000-2004 to evaluate the manurial potential of different distillery effluents, *i.e.*, spent wash (SW), post-methanation effluent (PME) and lagoon sludge (LS) *vis-avis* recommended fertilizers (NPK +FYM) in groundnut-wheat and maize-chickpea systems. It was found that all the three products of distillery effluent improved the performance of the crop by increased crop growth rate (CGR), total chlorophyll content, dry matter production, and thereby seed yield compared to control (Tables 14-21) . Among the three distillery effluents studied, PME produced the highest seed yield followed by SW and LS. PME produced almost two times the seed yield of control. However, distillery effluents inhibited nodulation and decreased the nitrogen fixation indicated by acetylene reduction assay in groundnut. Further, protein and oil contents were not influenced by the application of distillery effluents. Nutrient uptake was also increased by application of distillery effluent. Nevertheless, the crop performance and yield was comparatively low compared to recommended fertilizers, *i.e.*, NPK + FYM because of poor nutrient availability to the plants for achieving their potential growth. It was concluded that, these distillery effluents because of their high manurial potential, could supplement nutrients to the crops, reduce the fertilizer requirement of crop, save the cost of fertilizer to the farmers and decrease the environmental pollution.

Table 14: Dry weight (g m^{-2}) and total chlorophyll (mg g fw^{-1}) of groundnut as affected by distillery effluents

Treatment	**Days after sowing**								
Dry	**Weight (g m^{-2})**					**Chlorophyll (mg g^{-1} fw)**			
	25	50	75	100	Harvest	25	50	75	100
Control	131	364	821	1466	1820	1.65	1.90	2.05	1.14
PME	101	579	1458	2546	3131	2.24	2.72	2.91	1.33
SW	98	475	1060	1874	2275	1.92	2.61	2.52	1.75
LS	130	743	1946	3284	3998	1.91	2.68	2.69	1.23
NPK+FYM	131	965	2374	3986	4735	2.35	2.94	3.12	1.76
CD(0.05)	*13*	*125*	*392*	*469*	*388*	*0.32*	*0.49*	*0.54*	*0.44*

Table 15: Effect of distillery effluent on nodulation and enzymatic activities in groundnut

Treatment	**No of nodules/ plant**	**Fresh weight of nodule (g/plant)**	**Nitrogenase (µ mol C_2H_4 / plant/hour)**	**NRA (nmol NO_2^-/g FW/hr)**		**Peroxidase (units/gFW)**		**Poly phenol oxidase (Units/g FW)**	
				1st stage	**IInd stage**	**Ist stage**	**IInd stage**	**Ist stage**	**IInd stage**
Control	131	0.86	256	274	300	602	506	76	149
PME	115	0.82	198	399	418	798	560	152	168
SW	77	0.61	140	235	263	763	499	126	158
LS	95	0.70	175	243	276	756	481	94	143
NPK+FYM	160	1.20	319	250	278	644	438	84	104
CD(0.05)	20	0.55	-	75	99	102	59	17	20

Table 16: Effect of distillery effluent on oil and protein content (%) in Groundnut

Treatment	Oil content (%)	Protein content (%)	Oil yield(q ha^{-1})	Protein yield(q ha^{-1})
Control	45.31	24.47	1.40	0.76
PME	45.53	26.44	4.29	2.45
SW	46.84	25.66	2.82	1.64
LS	47.37	24.91	2.61	1.43
NPK+FYM	47.62	24.97	2.24	1.18
CD (P=0.05)	*NS*	*NS*	-	-

Table 17: Effect of distillery effluent on total chlorophyll (mg g FW^{-1}) and total dry matter production in 1 meter running length of maize

	Days after sowing								
Treatment	Total chlorophyll				Total dry matter production				
	20	40	60	80	20	40	60	80	Harvest
Control	1.84	2.14	2.36	1.96	6.1	58.8	188.5	377.2	611.5
PME	2.25	2.92	3.14	2.24	11.7	129.7	432.2	717.0	1054.7
SW	2.32	3.09	3.33	2.22	10.2	116.9	348.1	615.7	924.1
LS	1.93	2.46	2.50	2.07	9.1	76.2	218.4	466.1	763.3
NPK+FYM	2.68	3.10	3.48	2.35	13.9	171.6	536.0	925.8	1351.3
CD (P=0.05)	*NS*	*0.51*	*0.34*	*0.05*	*1.2*	*16.6*	*42.3*	*221.8*	*313.6*

Table 18: Effect of distillery effluent on uptake of N, P and K (kg ha^{-1}) in maize

Treatment	N	P	K
Control	33.4	4.3	42.4
PME	60.6	8.6	86.0
SW	48.3	6.1	78.1
LS	44.5	9.0	68.4
NPK+FYM	83.4	14.1	138.6
CD (P=0.05)	22.7	3.5	21.6

Table 19: Effect of distillery effluent on total chlorophyll (mg g FW^{-1}) and total dry matter production (kg) in 1 meter running length maize

Treatment	Days after sowing								
	Total chlorophyll				Total dry matter production				
	20	40	60	80	20	40	60	80	Harvest
Control	1.84	2.14	2.36	1.96	6.1	58.8	188.5	377.2	611.5
PME	2.25	2.92	3.14	2.24	11.7	129.7	432.2	717.0	1054.7
SW	2.32	3.09	3.33	2.22	10.2	116.9	348.1	615.7	924.1
LS	1.93	2.46	2.50	2.07	9.1	76.2	218.4	466.1	763.3
NPK+FYM	2.68	3.10	3.48	2.35	13.9	171.6	536.0	925.8	1351.3
CD(0.05)	*NS*	*0.51*	*0.34*	*0.05*	*1.2*	*16.6*	*42.3*	*221.8*	*313.6*

Table 20 : Distillery wastes on crop yields (Mg ha^{-1})

Treatment	Maize			Chickpea		
	Min	Max	Mean	Min	Max	Mean
Control	1.78	2.63	2.32	0.43	1.23	0.89
NPK-FYM	4.09	6.91	5.32	1.07	2.01	1.66
SW	2.33	4.44	3.63	0.74	1.04	0.87
PME	3.0	6.12	4.50	0.91	1.72	1.33
LS	1.99	6.58	4.01	1.26	1.93	1.67
CD (P= 0.05	-	-	*1.31*	-	-	*0.36*

Table 21: Distillery wastes on crop yields (Mg ha^{-1})

Treatment	Groundnut			Wheat		
	Min	Max	Mean	Min	Max	Mean
Control	0.17	0.43	0.29	0.83	2.44	1.55
NPK-FYM	0.31	0.90	0.60	2.47	5.54	3.78
SW	0.23	0.59	0.41	1.21	3.02	1.68
PME	0.27	0.97	0.54	1.66	4.36	2.87
LS	0.25	0.65	0.43	1.77	4.93	2.64
CD (P= 0.05	-	-	*0.19*	-	-	*1.13*

6.6.2 *Chlorophyll and NR activity in maize*

The application of different distillery wastes, namely, PME, SW and LS increased total chlorophyll content (Table 22) and leaf area resulting in higher dry matter production (data not presented) in maize reflecting their high manurial potential. The chlorophyll content and leaf area increased up to 60 days after sowing with the application of effluents and subsequently decreased mainly due to the on set of senescence. Among the distillery effluents, PME produced the highest dry matter followed by SW and LS. However, the recommended NPK+FYM was significantly superior in dry matter accumulation among all the treatments. Further, the nitrate reductive activity also increased with the application of the effluents compared to control (Table 22).

Table 22: Effect of distillery wastes on total chlorophyll and nitrate reductase activity

Treatment	**Days after sowing**				
	Total chlorophyll (mg g FW^{-1})				**NR Activity (mol NO_2^- g FW h^{-1})**
	20	**40**	**60**	**80**	**60**
Control	1.84	2.14	2.36	1.96	76.1
NPK+FYM	2.68	3.10	3.48	2.35	143.2
PME	2.32	3.09	3.33	2.22	114.1
SW	2.25	2.92	3.14	2.24	101.4
LS	1.93	2.46	2.50	2.07	103.8
CD(P=0.05)	*NS*	*0.51*	*0.34*	*0.05*	*37.6*

6.6.3 *Yield performance of soybean-wheat at graded levels of SW and PME*

The mean yield of soybean averaged over for a period of five years as influenced by SW and PME application was at par with NPK+FYM (Table 23 & 25). Soybean seed yield at all levels of SW and PME application was much higher than control. However, level of SW and PME application had no effect on mean yield of soybean. The variability in yield of soybean from year to year was due to availability of adequate rainfall as soybean was grown as rainfed.

The highest mean grain yield of wheat was obtained with recommended dose of NPK applied to wheat followed by NPK+FYM applied to soybean (Table 23 & 25).

SW and PME application to soybean had substantial residual effect on wheat, as wheat grain yield without any fresh application of SW to wheat was significantly higher than control. Fresh application of SW and PME, however, had significant effect on wheat yield.

Application of SW and PME to soybean brought down the harvest indices of soybean to a great extent, which was significantly lower than control and NPK+FYM. In case of wheat, only the highest level of SW application had lower harvest index than control (Table 24 & 26).

Table 23: SW on crop yields (Mg ha^{-1})

Treatment		**Soybean**			**Wheat**		
Soybean	**Wheat**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Control	Control	1.07	1.55	1.36	0.76	2.70	1.69
NPK+FYM	NPK	1.27	2.66	2.16	1.54	5.93	3.91
SW 2.5	Residual	1.47	2.41	2.03	1.61	3.38	2.75
SW 2.5	SW 1.25	1.43	2.65	2.14	1.72	4.04	3.25
SW 5.0	Residual	1.81	2.52	2.14	2.08	4.34	3.11
SW 5.0	SW 2.5	1.76	2.59	2.18	1.79	4.82	3.29
CD (P = 0.05		-	-	*0.48*	-	-	*0.65*

Table 24: SW on harvest indices

Treatment		**Soybean**			**Wheat**		
Soybean	**Wheat**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Control	Control	0.37	0.41	0.39	0.32	0.35	0.33
NPK+FYM	NPK	0.35	0.39	0.37	0.28	0.39	0.31
SW 2.5	Residual	0.32	0.35	0.33	0.31	0.31	0.31
SW 2.5	SW 1.25	0.30	0.35	0.33	0.29	0.39	0.31
SW 5.0	Residual	0.29	0.31	0.30	0.28	0.39	0.31
SW 5.0	SW 2.5	0.27	0.31	0.29	0.27	0.36	0.29
CD (P = 0.05		-	-	*0.05*	-	-	*0.03*

Table 25: PME on crop yields (Mg ha^{-1})

Treatment		Soybean			Wheat		
Soybean	Wheat	Min	Max	Mean	Min	Max	Mean
Control	Control	1.07	1.55	1.36	0.76	2.70	1.69
NPK+FYM	NPK	1.27	2.66	2.16	1.54	5.93	3.91
PME 2.5	Residual	1.61	2.28	1.97	1.14	2.92	2.11
PME 2.5	PME 1.25	1.56	2.42	2.01	1.64	4.77	2.92
PME 5.0	Residual	1.87	2.81	2.20	1.18	3.76	2.57
PME 5.0	PME 2.5	1.71	2.88	2.23	1.40	6.42	3.13
PME 10.0	Residual	2.02	2.91	2.25	1.21	4.40	2.80
PME 10.0	PME 5.0	1.59	2.42	2.04	1.18	7.46	3.45
CD (P = 0.05)		-	-	*0.42*	-	-	*0.62*

Table 26: PME on harvest indices

Treatment		Soybean			Wheat		
Soybean	Wheat	Min	Max	Mean	Min	Max	Mean
Control	Control	0.37	0.41	0.39	0.32	0.35	0.33
NPK+FYM	NPK	0.35	0.39	0.37	0.28	0.39	0.31
PME 2.5	Residual	0.32	0.41	0.36	0.29	0.35	0.30
PME 2.5	PME 1.25	0.30	0.41	0.35	0.24	0.35	0.28
PME 5.0	Residual	0.30	0.33	0.31	0.28	0.34	0.30
PME 5.0	PME 2.5	0.29	0.36	0.32	0.20	0.39	0.27
PME 10.0	Residual	0.28	0.36	0.31	0.24	0.38	0.27
PME 10.0	PME 5.0	0.27	0.35	0.30	0.22	0.41	0.26
CD (P = 0.05)		-	-	*0.02*	-	-	*0.03*

6.6.4 Biochemical parameters of soybean

The application of higher doses of PME even up to 10.0 cm did not show any toxic effect on soybean leaves. The PME application to the soil resulted in production of broader and dark green leaves with higher chlorophyll content (Table 27). Further, the application of PME significantly increased the nitrate reductase (NR) activity in all the three stages of crop growth. Among the three stages, the activity of NR was the highest in the pre-flowering stage and declined thereafter in all the treatments. The activity of the enzyme increased with an increase in the dose of the effluent. A similar trend was observed with the nitrate content of the leaf tissue and rhizosphere soil as well (Table 27). The presence of higher amount of total nitrogen in the PME applied could be the possible reason for the higher activity of the enzyme. On the other hand, the PME inhibited nodulation. This adverse effect on nodulation was high at higher doses of PME (Table 27). The suppression of nodulation could be attributed to high concentration of salts (EC 25.6 dS m^{-1}) which may have been toxic to *Rhizobium* populations thereby affecting the nodulation process and nitrogen fixation. The application of PME did not show any significant effect on oil (16.24-16.70%), protein (35.66-37.88%), and mineral (4.92-5.16%) contents, but increased the sulphur containing amino acids, methionine and cystine, in soybean seed (Table 28).

Table 27: Effect of PME on total chlorophyll content, number of nodules, NR activity, nitrate content of leaf tissue and rhizosphere soil in soybean at flowering

Treatment	Total Chl (mg g FW^{-1})	Nodule No./plant	NR Activity (mol NO_2^- g FW h^{-1})	Nitrate content of leaf tissue (mol NO_2^- g FW h^{-1})	Nitrate content of rhizosphere soil (mol NO_2^- $g^{-1}h^{-1}$)
Control	2.83	82	108.9	76.1	48.4
NPK+FYM	3.15	119	117.4	84.8	72.4
PME 2.5	3.44	54	157.3	174.5	78.1
PME 5.0	3.60	35	178.4	132.4	95.6
PME 10.0	3.66	32	289.3	174.5	104.4
CD (P=0.05)	*0.32*	*22*	*48.7*	*52.3*	*24.2*

6.6.5 Changes in soil properties under maize-chickpea and groundnut-wheat systems

Changes in some important physico-chemical properties and fertility parameters of soil under maize-chickpea and groundnut-wheat systems due to application of the distillery wastes have also been monitored at the end of fifth cropping cycle. There was no significant change in pH due to the application of distillery wastes, but a slight build-up of salinity as indicated by EC of the soil took place by 0.12 units as compared to control under maize-chickpea (Table 29). Salinity build-up was less under groundnut-wheat system as compared to maize-chickpea. The OC content of the soil has also increased with the application of these wastes, a high of 0.66% being in PME treated plots and a low of 0.59% in SW and LS treated plots, which were at par with NPK+FYM treatment (0.53%) and significantly higher than control (0.48%) under maize-chickpea. Under groundnut-wheat system, all three wastes behaved almost similarly with NPK+FYM in improving the OC content of the soil (Table 29).

Table 28: Effect of PME on oil, protein and mineral contents in soybean

Treatment	**Oil (%)**	**Protein (%)**	**Mineral (%)**	**Methionine ($g\ 16\ g\ N^{-1}$)**	**Cystine ($g\ 16\ g\ N^{-1}$)**
Control	16.24	35.90	4.96	1.22	1.10
NPK + FYM	16.47	36.91	5.01	1.29	1.12
PME 2.5	16.70	35.66	4.92	1.38	1.22
PME 5.0	16.36	35.63	5.16	1.45	1.31
PME 10.0	16.52	37.88	5.14	1.56	1.45
CD(P=0.05)	NS	*NS*	*NS*	*0.14*	*0.10*

Table 29: Changes in some soil properties at the end of the five cropping cycles

Treatments	**Maize-Chickpea**			**Groundnut-Wheat**		
	pH	**EC**	**OC (%)**	**pH**	**EC**	**OC (%)**
Control	8.1	0.46	0.48	8.2	0.48	0.49
NPK+FYM	8.0	0.51	0.53	8.1	0.48	0.64
PME(0.5cm)	7.9	0.52	0.59	7.9	0.53	0.64
PME(1.0cm)	8.0	0.56	0.66	8.0	0.56	0.57
LS (5 t ha^{-1})	7.9	0.55	0.59	8.1	0.50	0.63
CD (P=0.05)	*NS*	*0.08*	*0.13*	*NS*	*0.07*	*0.11*

Available N, P and K contents of the soil were measured at the end of third cropping cycle to evaluate the effect of distillery wastes on soil fertility status under maize-chickpea and groundnut-wheat systems (Table 30). There was no significant change in available N status of the soil in both the cropping systems with the addition of distillery wastes. Available P and K status of the soil increased to a great extent over control due to distillery wastes in both systems. While LS treated plots recorded the highest available P status of the soil, PME recorded the highest available K status of the soil. There was quite a significant accumulation of available K in the soil in proportion to the level of addition of these waste products at the end of third cropping cycle (Table 30).

Table 30: Changes in some soil fertility parameters (kg ha^{-1}) at the end of five cropping cycles

Treatments	Maize-Chickpea			Groundnut-Wheat		
	Av.N	Av.P	Av.K	Av.N	Av.P	Av.K
Control	208.3	5.6	388.8	188.1	6.6	431.7
NPK+FYM	250.8	19.9	687.2	229.9	14.0	584.6
PME(0.5cm)	253.7	13.1	810.4	188.1	17.6	818.9
PME(1.0cm)	205.0	13.6	1011.5	191.0	20.0	1015.5
LS (5 t ha^{-1})	221.8	27.6	641.9	213.3	21.2	656.3
CD (P=0.05)	*NS*	*NS*	*213.4*	*NS*	*NS*	*165.9*

Movement of N, P and K in the soil was also monitored by evaluating changes in available N, P and K status of the soil up to a depth of 60 cm at the end of third cropping cycle. Irrespective of the cropping systems, there was no significant change in available N status of the soil at lower depths due to distillery wastes vis-à-vis NPK+FYM and control (Table 31). There was some improvement in terms of available P status of the soil in the subsurface layer (15-30cm), although the waste treatments had no significant effect over and above control and NPK+FYM. Cropping systems also had no effect on the profile distribution of available P (Table 32). Unlike N and P, available K status in the sub-surface soils improved considerably with distillery wastes and NPK+FYM as compared to control. However, amongst the wastes there was no significant difference in this regard and all three wastes were at par with NPK+FYM (Table 33).

Table 31: Changes in available N status (kg ha^{-1}) in soil profile at the end of five cropping cycles

Treatments	Maize-Chickpea			Groundnut-Wheat		
	0-15 cm	15-30cm	30-60 cm	0-15 cm	15-30cm	30-60 cm
Control	208.3	143.4	122.9	188.1	125.3	102.4
NPK+FYM	250.8	163.9	163.9	229.9	177.7	143.4
PME(0.5cm)	253.7	143.4	163.9	188.1	117.7	125.3
PME(1.0cm)	205.0	143.4	143.4	191.0	122.9	164.0
LS (5 t ha^{-1})	221.8	125.3	143.4	213.3	140.6	130.5
CD (P=0.05)	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

Table 32: Changes in available P status (kg ha^{-1}) in soil profile at the end of five cropping cycles

Treatments	Maize-Chickpea			Groundnut-Wheat		
	0-15 cm	15-30cm	30-60cm	0-15cm	15-30cm	30-60cm
Control	5.6	6.4	5.9	6.6	6.3	5.5
NPK+FYM	19.9	11.5	4.7	14.0	13.7	5.5
PME(0.5cm)	13.1	8.7	5.4	17.6	12.7	3.8
PME(1.0cm)	13.6	8.7	4.7	20.0	12.8	4.0
LS (5 t ha^{-1})	27.6	10.1	4.8	21.2	11.9	5.1
CD (P=0.05)	*8.2*	*NS*	*NS*	*7.8*	*NS*	*NS*

Table 33: Changes in available K status (kg ha^{-1}) in soil profile at the end of five cropping cycles

Treatments	Maize-Chickpea			Groundnut-Wheat		
	0-15 cm	15-30cm	30-60cm	0-15cm	15-30cm	30-60cm
Control	388.8	330.5	391.4	431.7	388.3	360.7
NPK+FYM	687.2	696.7	582.4	584.6	675.3	592.8
PME(0.5cm)	810.4	650.7	617.8	818.9	594.7	582.7
PME(1.0cm)	1011.5	678.7	622.3	1015.5	679.5	613.0
LS (5 t ha^{-1})	641.9	655.9	574.9	656.3	580.6	533.7
CD (P=0.05)	*213.4*	*292.5*	*212.4*	*165.9*	*203.8*	*198.7*

6.6.6 *Changes in soil properties under soybean-wheat system*

Changes in physical properties of the soil upon continuous application of PME and SW were monitored at the end of five cropping cycles (Table 34 & 35). The application of PME showed a significant improvement in the physical properties of the soil. The mean weight diameter (MWD), per cent water stable aggregation (% WSA), saturated hydraulic conductivity (K_{sat}) and water retention (WR) at 0.033 MPa suction were significantly ($P < 0.05$) more while bulk density (BD) and penetration resistance was significantly less in PME treated plots than that of control. Maximum MWD (1.06 mm) and K_{sat} (36.8×10^{-6} ms^{-1}) were recorded in $S_{10.0}+W_{5.0}$ while these were minimum, 0.52 mm and 8.5×10^{-6} ms^{-1}, in control. The MWD showed a linear and positive relationship (r=0.89**) with the organic carbon content of the soil.

Table 34: Changes in some soil physical properties due to PME application at the end of the five cropping cycles

Treatments		MWD	%	BD	K_{Sat}	WR at 0.33
Soybean	**Wheat**	**(mm)**	**WSA**	**(Mg m^{-3})**	**($x10^{6}$ ms^{-1})**	**bar (w/w)**
Control	Control	0.52	39.98	1.29	8.5	25.8
NPK+FYM	NPK	0.66	43.34	1.22	15.6	27.1
PME2.5	Residual	0.63	41.06	1.24	14.7	26.7
PME2.5	PME1.25	0.78	46.25	1.19	22.6	28.2
PME5.0	Residual	0.74	45.86	1.20	18.3	28.5
PME5.0	PME2.5	0.98	52.88	1.13	30.3	29.6
PME10.0	Residual	0.86	48.66	1.16	24.5	29.2
PME10.0	PME5.0	1.06	51.54	1.09	36.8	31.4
LSD		0.11	-	0.06	6.7	1.5

The application of SW also showed a significant improvement in the physical properties of the soil. The mean weight diameter (MWD), per cent water stable aggregates, saturated hydraulic conductivity and water retention at saturation and 0.033 MPa suction were significantly ($P<0.05$) more, while bulk density (BD) and penetration resistance were significantly less ($P<0.05$) in all the DE treated plots except in SW2.5 + residual than those of control and NPK + FYM treatments. The MWD showed a positive linear relationship (r = 0.90**) with the organic carbon content of the soil.

Table 35: Changes in some soil physical properties due to SW application at the end of the five cropping cycles

Treatments		MWD	%	BD	S at HC	WR at 0.33
Soybean	Wheat	(mm)	WSA	(MG m^{-3})	(x10^{6} ms^{-1})	bar (w/w)
Control	Control	0.50	44.9	1.29	9.5	24.1
NPK+FYM	NPK	0.68	48.2	1.22	18.8	27.3
SW 2.5	Residual	0.81	50.5	1.21	17.5	27.4
SW 2.5	SW 1.25	0.96	53.3	1.17	29.6	28.3
SW 5.0	Residual	1.01	54.0	1.18	33.5	28.6
SW 5.0	SW 2.5	1.14	63.9	1.13	38.9	30.5
LSD		0.11	-	0.05	7.5	2.6

A perusal of data on pH, EC, OC, available P and K content of soil at the end of five cropping cycles (Table 36) shows that except soil reaction (pH) all other parameters changed in the positive direction due to SW and PME application, which were significantly higher than control and either at par or higher than NPK+FYM treatment. Of much significance is the salinity build-up at higher level of SW and PME addition. There was significant improvement in fertility of the soil due to SW and PME application as indicated by OC, available P and K (Table 36), and available S, Zn, Cu, Fe and Mn (Table 37) content of the soil at the end of five cropping cycles. Barring a few exceptions, there were significant improvements in bio-chemical properties of the soil, namely, soil microbial biomass C, soil respiration, and activity of dehydrogenase, alkaline phosphatase and cellulase enzymes, due to SW and PME application (Table 38).

The results showed that application of distillery effluents caused significant improvement in the physical environment, fertility status and biological condition of the soil, and recorded considerable yield advantages over control and 100% recommended dose of fertilizer plus manure treatment for soybean, wheat, maize and chickpea. However, increase in EC was a cause of concern in high level of effluent application. Effluent application up to 5 ha-cm level was found to be optimum from yield, salinity and sustainability point of view. The study thus indicated that application of distillery wastewater to the agricultural field, as an amendment, might be a viable option for the safe disposal of this industrial waste with concomitant

Table 36: Some physico-chemical and fertility parameters of the soil at the end of five cropping cycles

Treatments		pH	EC	OC	Av. P	Av. K
Soybean	**Wheat**	**(1:2.5)**	**(dS m^{-1})**	**(g kg^{-1})**	**(mg kg^{-1})**	**(mg kg^{-1})**
Control	Control	8.1	0.44	4.2	3.0	212
NPK+FYM	NPK	8.1	0.65	7.9	8.5	409
PME 2.5	Residual	8.0	0.71	8.9	5.2	654
PME 5.0	Residual	8.1	0.79	9.4	9.5	852
PME 10.0	Residual	8.2	0.93	11.4	14.6	1498
SW 2.5	Residual	8.1	0.66	10.0	10.8	782
SW 5.0	Residual	8.1	0.83	11.1	14.1	1478
CD (P = 0.05)	*NS*	*0.05*	*0.06*	*2.8*	*73*	

Table 37: Some fertility parameters of the soil at the end of five cropping cycles

Treatments		Av. S	Av. Zn	Av. Cu	Av. Fe	Av. Mn
Soybean	**Wheat**	**(mg kg^{-1})**	**(mg kg^{-1})**	**(mg kg^{-1})**	**(mg kg^{-1})**	**(mg kg^{-1})**
Control	Control	5.6	0.56	1.93	7.1	11.1
NPK+FYM	NPK	14.2	2.29	3.26	28.4	44.3
PME 2.5	Residual	42.8	1.50	2.57	15.3	39.4
PME 5.0	Residual	59.8	2.19	3.18	24.2	41.3
PME 10.0	Residual	82.6	5.19	5.30	45.3	56.3
SW 2.5	Residual	152.4	1.30	2.27	21.4	36.7
SW 5.0	Residual	290.6	2.02	2.85	23.2	38.5
CD (P = 0.05)	*22.8*	*0.17*	*0.12*	*2.3*	*2.3*	

improvement in crop productivity and quality of the soil. However, the level of distillery effluent application should be within the prescribed limit to avoid probable development of soil salinity in the effluent treated fields due to its high salt load.

Table 38: **Some bio-chemical parameters of the soil at the end of five cropping cycles**

Treatments		SMBC (mg kg^{-1})	Soil respiration (mg C kg^{-1})	Dehydrogenase (ug TPF g^{-1})	Alk. Phosphatase (ug p= NP g^{-1})	Cellulase (umol glucose g^{-1})
Soybean	**Wheat**					
Control	Control	1004	736	260	236	32.3
NPK+FYM	NPK	1253	1324	387	253	43.3
PME 2.5	Residual	1028	804	273	249	39.5
PME 5.0	Residual	1152	777	335	252	42.3
PME 10.0	Residual	1507	925	483	252	43.3
SW 2.5	Residual	1098	924	276	250	49.7
SW 5.0	Residual	1476	1160	373	251	54.5
CD (P = 0.05)		*54*	*89*	*8*	*3*	*1.2*

7. Use of Distillery Effluents in Compost Making

Spent wash has vast potential for its practical application in agriculture as a source of plant nutrients and organic matter and as an amendment for sodic soils. However, high transportation and labour costs for loading and unloading restrict their wider use beyond the sugar factory and the distillery zone. Hence, there is a need for transforming the liquid effluent into solid form to make its transportation easier and cheaper. Moreover, on the face of scarcity of water in semi-arid tropics of India there is need for looking alternate source of water for compost making, and spent wash being an organic carbon rich wastewater can be utilized perfectly. In view of this, a new process of composting has been developed at IISS, Bhopal by replacing water with distillery effluent. The compost was prepared by heap method using the standard procedure developed at the Institute except that water was replaced with spent wash. This has not only saved precious little water but also enriched the compost with useful nutrients like N, P, K, S and enzyme activity, apart from other growth promoting substances available in the effluent. Crop performance of this compost was tested in maize-chickpea system in a black soil The composition of spent wash amended compost at different sampling period is given at Table 39.

Table 39: Composition of spent wash amended compost at different sampling period

Sampling Details	Ash (%)	Total N (%)	Total P (%)	Total K (%)	C:N
Ist Sampling*					
Control	54.55	1.13	1.22	1.05	23.33
Before SW addition	61.80	1.03	1.23	1.13	20.95
After SW addition	60.73	1.09	1.49	1.66	20.89
2nd Sampling*					
Control	60.07	1.37	1.08	1.23	16.90
Before SW addition	70.37	0.89	1.24	1.26	19.31
After SW addition	70.83	0.99	1.25	1.52	17.45
3rd Sampling*					
Control	66.88	1.31	1.08	1.03	17.00
Before SW addition	64.74	1.16	1.28	1.57	17.60
After SW addition	66.33	1.37	1.30	1.82	14.25

* 1st, 2nd and 3rd samples were taken one, two and three months after composting.

7.1 Composting techniques

Distillery effluents can be used as a source of water for composting voluminous solid wastes like cattle dung, crop residues, press mud, etc. Besides maintaining moisture required during composing distillery effluents can supply important plant nutrients like K, S and micronutrients thus enriching the compost. In the last decade, composting press mud along with distillery effluents has become extremely popular. Standard procedure/method followed in a typical composting process is given below:

1st to 10th Day: Collection, mixing and hauling of material. Formation of heap or filling of pit layer by layer and turning of materials from time to time. Maintain moisture at 50% by spraying distillery effluents over heap or pit.

10th to 45th Day: Maintenance of moisture between 50-60% through spraying of distillery effluents. Temperature may rise up to 60-70° C at the peak of composting process. Turning up and homogenizing at regular intervals.

45th to 75th Day: Inoculation with microbial consortia containing bacteria, actinomycetes and filamentous fungi. Spraying 70 – 80 L distillery effluent per tonne of solid wastes twice everyday along with homogenizing of the material. Repeat the process for 20-25 days.

75th to 90th Day: Curing, aging and drying. Spraying distillery effluents is stopped at 60th day and compost is allowed to cure and age until moisture stabilizes at 25-30%.

In this process further enrichment of compost may be done by using amendments like rock phosphates, pyrites, waste mica, etc. Reports suggest that at moderate level of distillery effluents application vermi-composting can also be done using similar techniques.

7.2 Spent wash amended compost on maize-chickpea system

The performance of spent wash amended compost was tested in a field experiment in maize-chickpea sequence. Chickpea was grown on residual fertility from the treatments received in maize during *kharif*. The SW amended compost performed at par with other compost and FYM in terms of grain yield of maize (Table 40). The grain yields of maize were 19.9, 16.9 and 18.9 q ha^{-1} with FYM (10 t ha^{-1}), compost (10 t ha^{-1}) and SW-compost (10t ha^{-1}), respectively, which were significantly higher than control (14.1 q ha^{-1}) but significantly lower than recommended NPKSZn (37.3 q ha^{-1}). Inclusion of a top dressing of 50% recommended N at maximum tillering stage improved the grain yield of maize to a significant extent, albeit lower than recommended NPKSZn. Although the performance of all organic treatments with or without 50% N was inferior to recommended NPKSZn, the residual effects of these treatments were at par with the recommended NPKSZn in chickpea (Table 40). The results clearly indicated that the rate of application of compost was not sufficient to supply N to maize crop, but it could supply K and S required by the crop. Moreover, distillery effluent could save a huge quantity of precious freshwater required during the course of composting. Hence, this technology could be of immense help in arid and semi-arid parts of the country to save little precious water for compost-making.

Table 40: Spent wash amended compost on yield (q ha^{-1}) performance of test crops

Treatments		Maize	Chickpea
Maize	**Chickpea**		
Control	Control	14.1	20.7
Recommended NPKSZn	Residual	37.3	22.8
FYM (10 t ha^{-1})	Residual	19.9	25.5
Compost (10 t ha^{-1})	Residual	16.9	23.0
SW Compost (10 t ha^{-1})	Residual	18.9	24.2
FYM (10 t ha^{-1}) + 50% N as topdressing (TD)	Residual	23.6	23.7
Compost (10 t ha^{-1}) +50% N as TD	Residual	21.9	23.2
SW Compost (10 t ha^{-1}) + 50% N as TD	Residual	23.2	24.9
CD (P=0.05)		*3.6*	*2.3*

8. Management Prescriptions for Use of Distillery Wastes

Based on the crop performances and long-term implications of use of different distillery wastes on soil physical, chemical and biochemical parameters, suitable management prescriptions have been devised for harmless utilization of these waste products in soybean-wheat (Table 41), maize-chickpea and groundnut-wheat systems in a deep black soil. On-farm demonstration is going on at the institute with the following prescriptions.

Table 41: Prescriptions for use of distillery wastes in soybean-wheat system

Sl.No.	Soybean (rainfed)	Wheat (one pre-sowing plus two post-sown irrigations)
P-1	2.5 cm SW	N & P Fertilizers only
P-2	2.5 cm SW	1.25 cm SW + two top-dressings of N (1/4N +1/4N)
P-3	2.5 cm PME	N & P Fertilizers only
P-4	2.5 cm PME	1.25cm PME + two top-dressings of N (1/4N +1/4N)
P-5	5 t ha^{-1} LS	N & P Fertilizers only
P-6	5 t ha^{-1} LS	10 t ha^{-1} LS + two top-dressings of N(1/4N +1/4N)

Note :SW = Spent Wash, PME = Post-Methanation Effluents, LS = Lagoon Sludges (RSW, PME and LS to be applied 7-15 days before sowing).

The contribution made on this aspect will not only lead to the development of a technology for safe disposal of otherwise polluting distillery effluents onto the agricultural lands for crop production, but also advance our knowledge on the risk assessment and environmental impact of long-term use of the effluents in soil in terms of changes in quality parameters of the soil and water.

9. Methods for Safe and Efficient Use

The environmental significance of distilleries is recognized as the polluting units generating large volume of foul smelling and colour wastewater known as spent wash. Generally, the waste water is discharged into the water courses under untreated or partially treated conditions. Sometimes, the spent wash is recycled to produce methane, which supplements the energy needs of the distillery as boiler fuel. Attempts have also been made to produce potash fertilizer from distillery effluents, in which the effluents is concentrated, dried and incinerated in specially designed multifed boilers. The energy generated can be used for the drying process or distillation and the steam can be used to generate power. Techniques have also been developed to use spent wash obtained from the distilleries for mass scale production of earthworms which are good soil conditioners and find use in agriculture. However, these technologies could not get enough public attention because the processes are not economically lucrative.

The best strategy for utilization of this effluent for fertigation of agriculture crops should emerge from the realization by all the concerned be it distilleries, pollution control agencies, farmers or research organizations that this effluent is a valuable resource which should not be wasted under any circumstances. Once the resource value of the effluent as a source of bioenergy and biomass is recognized, all agencies can work together to explore the possibilities for harnessing full potential of the effluent.

The use of spent wash for pre-sown treatment of agricultural land which has been practiced for last five decades and studies by various workers all over the world, although seems to be lucrative, should be discontinued as the productions of biogas from it offers a cheap and pollution free source of energy. Attracted by economic returns most of the distilleries have already installed biomethanation digesters and the remaining units are in the process of putting up these units. The post methanation effluent has lower C: N ratio and it would degrade more swiftly in the soil than spent wash. Hence, there should not be any problem with its use in agriculture.

The volume of the effluent is enormous. For a distillery with 30 kld alcohol production capacity not less than 270 ha of land are required. Such large area of land may not be available with the distilleries or even with a single farm house. In such case more than one farm holding (sometimes number may even go over 50) have to be brought together to utilize the effluent. A cooperative system has to be evolved which is crucial for the success of such programme. Distilleries have to provide lined irrigation channels to reach farmers' fields so as to make the package attractive for farmers.

Land treatment or agro-recycling of the distillery effluent is a convenient process but sometimes it is impracticable due to non-availability of sufficient land area or dilution water. In such situations the effluent can be transformed into a bio-fertiliser for which costly but viable technologies are available. Composting with pressmud and vermiculture are a few alternatives which can be ventured to utilize the manurial potential of the distillery effluent.

10. Summary and Conclusions

In India, sugar is produced by using techniques that are not used anywhere in the world and it produces a waste product, i.e. molasses which is the worst in quality with respect to environmental parameters. As most of the distilleries in India use molasses as the material for fermentation, the effluent generated from them is most difficult to treat. A number of process packages on biomethanation of distillery spent wash have been developed abroad. The planned efficiencies of the processes are likely to suffer when they are applied to Indian distilleries. However, national organizations like NEERI, Nagpur and some corporate houses involved in distillation business have undertaken research activities to make these processes compatible to Indian conditions.

The anaerobic digestion is followed by secondary treatment requiring continued aeration which is an energy intensive exercise. Due to non-availability of electricity, usually the effluent stagnates untreated in the retention ponds causing odour and ground water pollution problem. It is therefore, imperative to explore the possibilities of using the post- methanation effluent coming out from the anaerobic digesters for other beneficial uses. Since the effluent contains substantial amount of essential nutrients like nitrogen, potassium and phosphorus, it is desirable that the effluent may be considered as a source of fertilizer and should find use in agriculture.

Farmers in Maharashtra and Andhra Pradesh are utilizing the distillery effluent primarily through direct spent wash application and making spent wash cakes or spent wash press mud compost, whereas in Uttar Pradesh the post methanation effluent is applied to the crops. In certain areas the scarcity of the water has forced the farmers to use the effluent as a substitute of irrigation water. Results obtained at IISS, Bhopal clearly brought out the fact that land application of distillery effluents at the prescribed rates would definitely improve soil health and productivity. It would be pragmatic to consider the land application of post methanation effluent as an effective waste treatment strategy which bears the potential to replace the expensive energy intensive secondary treatment.

11. Epilogue

One of the most important environmental problems faced by the world is management of wastes. Now-a-days emphasis is laid on waste minimization and revenue generation through byproduct recovery. Pollution prevention focuses on preventing the generation of wastes, while waste minimization refers to reducing the volume or toxicity of hazardous wastes by water recycling and reuse.

The cost of effluent treatment in distilleries is likely to be compensated substantially by availability of methane gas. Effluent application will reduce the nutrient requirement through fertilizers. However, high salt load, mainly potassium and sulphur, into the soil system may hamper the sustained crop yields due to continued long-term application of effluent. Therefore the effect on crop productivity has to be visualized on long-term and sustainable basis. Application of post methanation effluent suitably diluted according to crop requirements and soil conditions seems to be a viable alternative.

The utilization of the distillery effluent in agricultural fields will not only enrich the soils with essential plant nutrients like nitrogen, phosphorus, sulphur and potash but also compensate the expenditure on fertilizers for crop growth. This practice will result in revenue generation and further lead to offsetting the costs substantially.

Similarly, spent wash utilization in bio-earth composting, where adequate land is available, being a simple process and not involving any heavy machinery is also one of the cost effective methods of disposal. Moreover, it is feasible alternative for utilization of treated effluent; as the same generates revenue thus offsetting the costs and further leading to reduction in pay back-period.

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